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DATE: 7 December 2005

TO: Tracy Tackett, Kathy Laughlin, SPU

CC: Joe Brascher

FROM: Doug Beyerlein, P.E.

SUBJECT: WWHM3 Eco-Roof Documentation

Introduction
We have added an eco-roof element to the Western Washington Hydrology Model version 3 (WWHM3) to accurately model the stormwater benefits of an eco-roof, in accordance to Work Assignment No. 1. The WWHM3 eco-roof element was tested using rainfall and runoff data obtained by SPU from the City of Portland's monitoring of the Hamilton Building in Portland, Oregon. WWHM3's eco-roof element reproduces the Portland data. The eco-roof element was then used to model a Seattle roof runoff and the results were compared with the runoff from a conventional roof. This memo describes the WWHM3 eco-roof element development, testing, conclusions, and recommendations.

WWHM3 Eco-Roof Element
The WWHM3 eco-roof element is a special lateral flow basin with unique characteristics. The element uses the HSPF hydrology algorithms to generate runoff, but the HSPF hydrology parameter values are modified to represent the eco-roof's shallow soil depth and lack of a groundwater reservoir. All runoff becomes stormwater, unlike in a conventional land basin where only the surface runoff and interflow contribute to stormwater and groundwater discharge (base flow) is not considered.

Theory
As described in the City of Portland's report (Hutchison, et al, 2004) an eco-roof is a living vegetated ecosystem of lightweight soil and self-sustaining vegetation. It provides a protective cover on the building by using the natural elements of sun, wind, and rain to sustain itself. Eco-roofs require little maintenance and provide an aesthetic alternative, with economic and ecological attributes not found in a conventional roof. Figure 1 shows the main eco-roof components including a waterproof membrane or material that prevents water from entering the building; drainage material such as geotextile webbing that allows water to

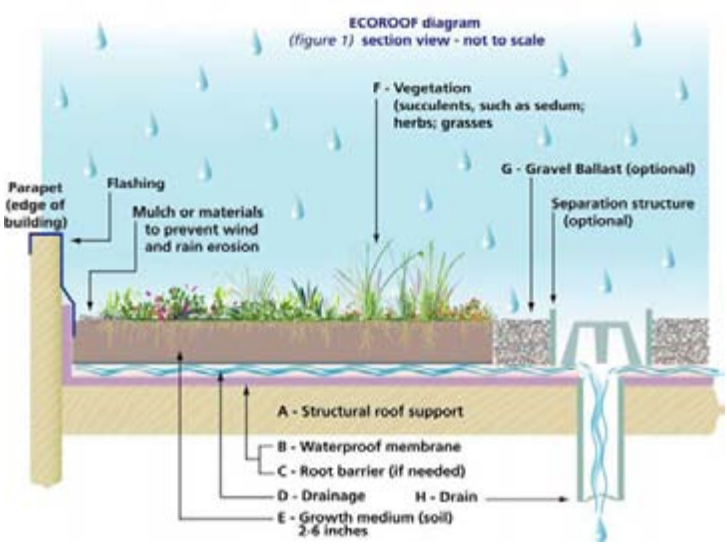

Figure 1. Schematic eco-roof cross section

flow to the drains when the substrate is saturated; and soil or substrate. Other terms used for eco-roofs are green roofs and vegetated roofs.

Assumptions

The assumptions used in the hydrologic modeling of eco-roofs are based on the standard hydrologic continuous simulation assumptions found in HSPF with the additional modifications to reflect eco-roofs' unique conditions.

The soil depth of an eco-roof is on the order of inches compared to feet for a natural soil column. Correspondingly, the hydrologic processes that take place in an eco-roof soil must be reduced in scale compared to those that take place in a natural soil column, although we make the assumption that the same hydrologic processes are still valid. This means that an eco-roof has an upper and lower soil zone. The upper soil zone generates surface runoff and interflow. The lower soil zone contributes groundwater/base flow. For an eco-roof it is assumed that the base flow moves through the soil to the drain at the same rate as the interflow.

All soil layers are available for evapotranspiration. That is one of the chief stormwater benefits of an eco-roof: increased evapotranspiration compared to a conventional roof. However, eco-roof evapotranspiration is still limited and is less than or equal to (but never greater than) the potential evapotranspiration. In Western Washington (and Western Oregon) the potential evapotranspiration in the winter months is relatively small compared to the rainfall due to nearly continuous saturated atmospheric conditions (in other words, it is wet all of the time).

Eco-roof vegetation may be irrigated during summer dry months, as is the case with Portland's Hamilton Building, but for the purposes of the WWHM3 testing it is assumed that stormwater impacts of summer irrigation are negligible and can be ignored. No eco-roof irrigation time series is provided to the user.

HSPF Parameter Values

The WWHM3 HSPF parameter values have been changed to represent the unique characteristics of the hydrology of an eco-roof (see Table 1). The changes were made based on the calibration of the HSPF parameter values to the Portland Hamilton Eco-roof monitoring data.

Table 1. Eco-Roof HSPF Parameter Values

HSPF Parameter	Eco-Roof Value	Standard WWHM3 Value*
LZSN	0.75/1.25**	4.50
INFILT	0.05	0.03
LSUR	50	400
SLSUR	0.001	0.050
AGWRC	0.100	0.996
AGWETP	0.80	0.00
UZSN	0.075/0.125**	0.250
NSUR	0.55	0.25
INTFW	1.0	6.0
IRC	0.10	0.50
LZETP	0.80	0.25

* Value for till soil, lawn, flat slope

** Values dependent on depth of material (values shown for Portland east and west roofs: 3 inches and 5 inches of material, respectively)

LZSN is the nominal (not maximum) lower soil zone storage (inches); eco-roofs have a smaller lower soil zone than a natural soil column because of their small soil depth.

INFILT is the infiltration index (inches per hour); based on the Portland data it is calibrated to a value slightly higher than used for till soils.
LSUR is the length (feet) of the overland flow path prior to collection into a conveyance system; the roof flow length is less than a natural flow length.

SLSUR is the slope (feet per foot) of the overland flow path; it is assumed that the roof top is very flat.

AGWRC is the groundwater recession constant (per day); for an eco-roof there is no groundwater and AGWRC is set equal to the interflow recession constant (IRC).

AGWETP is the groundwater evapotranspiration parameter (dimensionless); for an eco-roof AGWETP is set equal to the lower zone evapotranspiration parameter (LZETP).

UZSN is the nominal (not maximum) upper soil zone storage (inches); eco-roofs have a smaller upper soil zone than a natural soil column and the eco-roof UZSN is set equal to one-tenth of LZSN.

NSUR is the roughness coefficient (dimensionless) of the overland flow path and is a function of the vegetation; for an eco-roof with varied vegetation NSUR is set slightly higher than for lawn conditions.

INTFW is the interflow parameter (dimensionless) and partitions the distribution of runoff between surface runoff and interflow; for eco-roofs INTFW is set low because of the small UZSN value; this produces more surface runoff and less interflow.

IRC is the interflow recession constant (per day); it is set to a low value to reflect the relatively fast interflow runoff response compared to natural soil conditions.

LZETP is the lower zone evapotranspiration parameter (dimensionless); for an eco-roof LZETP is set equal to a relatively high value to represent the ability of the vegetation's root system to transpire water from the lower soil zone.

All of these eco-roof parameter values were developed through the process of testing the WWHM3 eco-roof element using the Portland Hamilton Building eco-roof monitored data, described below.

<u>WWHM3 Eco-Roof Screen</u>
The WWHM3 eco-roof screen is shown in Figure 2 below. As shown on the screen, the user has the option to enter the following information about the eco-roof:

Depth of Material (inches): Growth medium/soil depth; used to determine potential soil moisture volume. Typical values are 2 to 4 inches.

Slope of Rooftop (ft/ft): Surface slope of rooftop. Flat slope should be set to a minimum slope of 0.001.

Vegetative Cover: The user can choose between ground cover, shrubs, and trees. Ground cover includes lawn/grass. Vegetative cover influences interception storage, evapo-transpiration, and surface roughness.

Length of Rooftop (ft): The length of the surface flow path to the roof drain; should not exceed the length of the rooftop, but may be less.

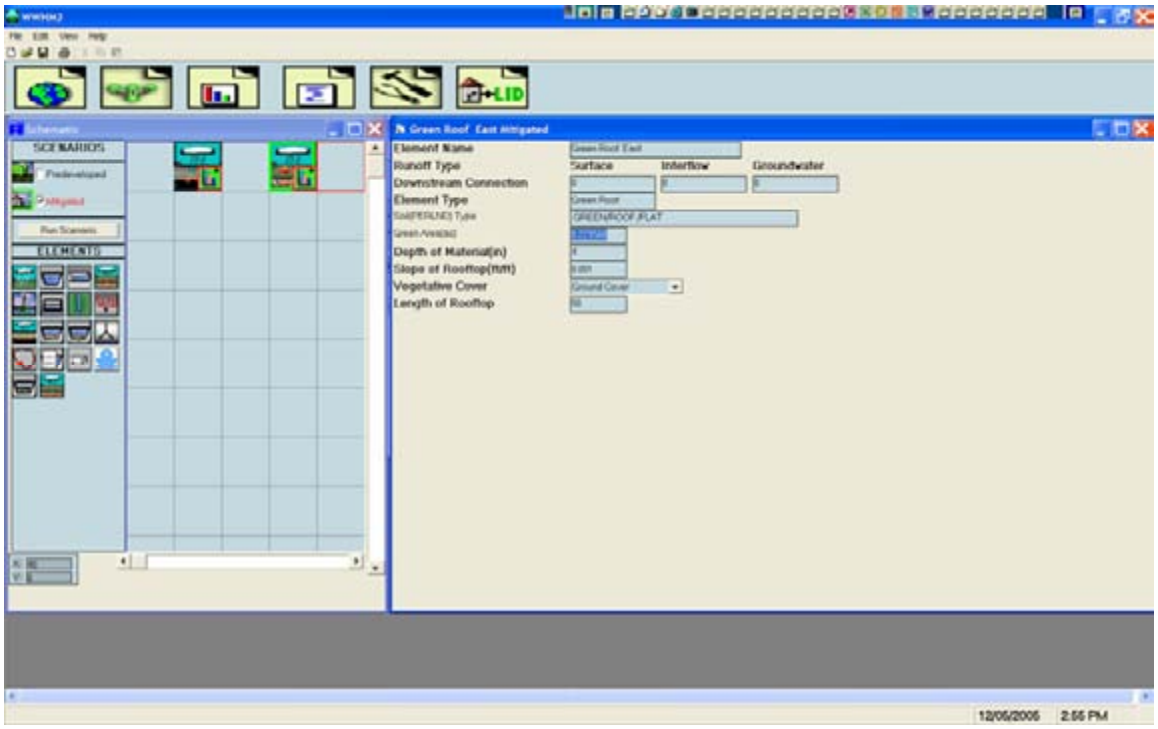

Figure 2. WWHM3 Eco-Roof Element.

Testing

The WWHM3 eco-roof element was tested using monitored rainfall and runoff data provided to SPU by the City of Portland, Bureau of Environmental Services (BES) for the Hamilton Apartment Building. The following monitoring description and accompanying figures are from the Portland report (Hutchison, et al, 2004).

Portland Hamilton Building

The Hamilton Apartments is a ten-story, 8,700 square foot (sf) building. The eco-roof was installed in September 1999. For research purposes, the eco-roof was divided into two sides: east and west. The east side consists of 2520 sf of vegetated cover with initial substrate depth of 3 inches (now 2 inches). The east substrate is composed of 15% digested fiber, 25% encapsulated Styrofoam (EPS), 15% perlite, 15% coarse peat moss and 15% compost. Saturated weight of the east substrate is 10 pounds per square foot (psf) for the original 3-inch depth. The west side consists of 2620 sf of vegetated cover with initial substrate depth of 5 inches (now 4-4.5 inches). The west substrate consists of 20% digested fiber, 10% compost, 22% coarse perlite and 28% sandy loam. Saturated weight of the west substrate is 25 psf for the original 5-inch depth. As of 2003, approximately one inch of substrate was lost on both sides due to wind erosion. An automatic irrigation system with spray heads on 12-inch risers was installed to water during dry periods. The irrigation system was installed to assure plant establishment, the long-term goal is to eliminate the need for irrigation. For example during the summer of 2001, about 6 and 4 inches of water was applied to the east and west sides, respectively; and in 2002 about 3 and 2 inches, respectively.

Figure 3. Hamilton East Eco-roof May 2002

As precipitation falls onto the building it flows laterally towards a set of primary and secondary roof drains located near the center of each of the two roof sections. The east drains have a total drainage catchment of 3,811 sf. This east catchment area consists of 2,520 sf of vegetated ecoroof (66%) and 1,291 sf of various impervious surfaces (34% impervious). The west drains have a total drainage catchment of 3,655 sf This catchment area consists of 2620 sf of vegetated eco-roof (72%) and 1,035 sf of various impervious surfaces (28% impervious) For both sides, the various impervious surfaces include vents, parapet walls, gravel on roof membrane, and terrace pavers installed over a 1.5-inch sand base to help absorb moisture.

There is a conventional roof on a 1,239 sf penthouse containing building heating and cooling equipment. In December 2001 all downspouts from the penthouse were plumbed directly to the primary roof drains so that conventional roof runoff would not combine with the vegetated areas. However, it is suspected that during high intensity storm events a 342 sf section of the penthouse roof drains into the east ecoroof due to lack of continuous gutters around the conventional roof. Figure 4 shows the roof layout.

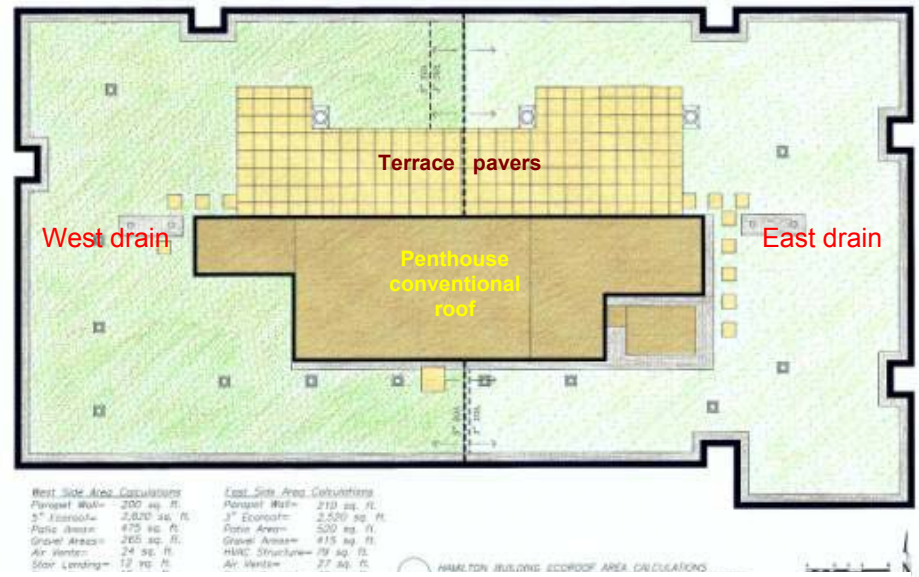

Figure 4. Hamilton Eco-roof Plan View

BES Field Operations staff installed flow-monitoring equipment in December 2001. A small, 60-degree, V-trapezoidal Plasti-Fab flume is installed adjacent to, and immediately upstream of, each primary roof drain. The primary roof drain is sealed and isolated to direct all flow through the flume prior to entering the drain. An American Sigma Model 950 bubbler-type flow meter is used to measure water level in each flume. Level data are converted to flow values by using a formula created by manually establishing the level to flow relationship specific to these flumes. Initial monitoring indicated that the formula provided for the flumes by the manufacturer was not accurate enough for this project so BES calculated a more accurate formula.

The primary roof drains are plumbed directly to the City storm sewer system. The adjacent secondary drains are installed as emergency overflow drains if the primary drains become plugged. Since the secondary drains are fitted with a two-inch extension collar, water will only enter the secondary drains if the pooled water level around the drains exceed 2.9 inches on the east side and 2.4 inches on the west side. The possibility exists that during very large storms, some water may flow out the secondary drain and not flow through the flume. To date, there has been only one storm that created enough runoff to cause overflow to the west secondary drain. The secondary drains discharge directly off the side of the building. Drainage from the conventional roof enters the primary drains immediately downstream from the flume outlets and is not monitored.

Figure 5. Flow monitoring station photographs. The left shows the flume and flow monitor and the right shows a close-up of the flume during a storm event.

A Hydrological Services tipping bucket rain gage was installed on top the conventional roof in the center of the building to ensure that accurate rain data are collected for the site. Rain data are collected and relayed via radio telemetry to a networked computer (HYDRA-system). Rain data are converted to a rain run-on flow rate for each side by multiplying rainfall by the catchment area.

The City of Portland produced their own analysis of the effectiveness of the two eco-roofs and that analysis will not be repeated in this tech memo. Instead the WWHM3 results will be compared with the City of Portland monitored data.

Figure 6. Rain gage and antenna in upper right.

WWHM3 Model Set-up

The Hamilton east and west eco-roofs were individually modeled. Each eco-roof receives lateral inflow from the adjacent impervious area. The runoff from the conventional penthouse roof was not modeled, nor was the overflow from the secondary drains, because of their minor and transitory effect on the eco-roof stormwater results.

As described above, the HSPF parameter values used in WWHM3 were modified to represent eco-roof conditions. Some parameters (LZSN, INFILT, INTFW, IRC) were calibrated to the Hamilton runoff. This is the standard procedure for determining these parameter values when previously calibrated parameter values do not exist.

Hamilton roof precipitation data for the period of December 27, 2001, through January 4, 2005, was obtained from the City of Portland BES. The precipitation data are 5-minute data, as are the runoff data from the east and west eco-roofs. The model simulation was also done at a 5-minute time step so as to directly compare model and monitoring results.

The WWHM3 requires potential or pan evaporation data for the same period as the precipitation data. The City of Portland does not collect pan evaporation data, so another local source was found. George Taylor at Oregon Climate Service was contacted and he recommended the use of AgriMet data provided by the U.S. Bureau of Reclamation (http://www.ocs.oregonstate.edu/index.html). The Aurora, Oregon, station was selected as the closest to Portland that had evaporation data. From the AgriMet web site computed Aurora Kimberly-Penman evapotranspiration data for the period of October 2001 through September 2005 was downloaded and used in the WWHM3 modeling of the Hamilton Building.

WWHM3 Model Results

The WWHM3 model results for the simulation of the Portland Hamilton east and west roofs were compared with the monitored runoff by plotting monitored vs. simulated hydrographs for both the entire period (December 27, 2001 through January 4, 2005) and for individual winter months (January 2002, January 2003, and January 2004). Figures 7 through 14 show the hydrographs.

In general the results show that the west roof is oversimulated (too much simulated runoff compared to monitored data) and the east roof is undersimulated (too little simulated runoff). There are two reasons for these differences.

The east and west eco-roofs are composed of different materials. As stated in the City of Portland report, “The east substrate is composed of 15% digested fiber, 25% encapsulated Styrofoam (EPS), 15% perlite, 15% coarse peat moss and 15% compost”. In contrast, the “west substrate consists of 20% digested fiber, 10% compost, 22% coarse perlite and 28% sandy loam.”

Initially we were able to achieve a more accurate calibration of each eco-roof by varying multiple HSPF parameter values for each roof to better reflect the different substrates. However, we later sought one set of parameter values that were the average of the two sets of values. We selected this course of action based on the need to provide the WWHM3 user with one representative set of values that can be used for a range of eco-roof soils and substrates. This decision impacts the accuracy of each calibration, but provides better general information for use in WWHM3.

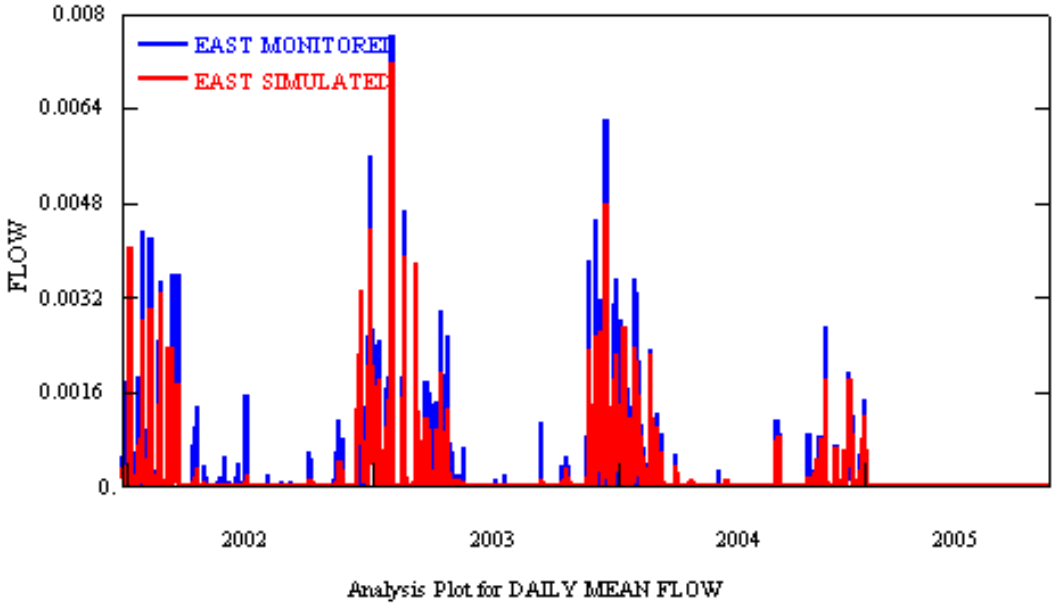

Figure 7. Portland Hamilton East Roof (2002-2005)

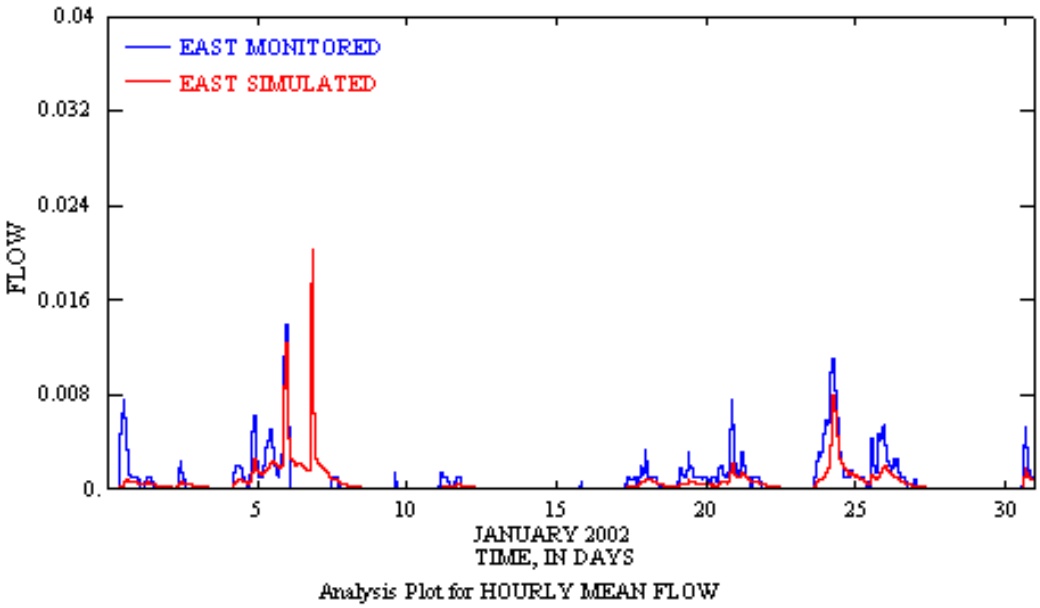

Figure 8. Portland Hamilton East Roof (January 2002)

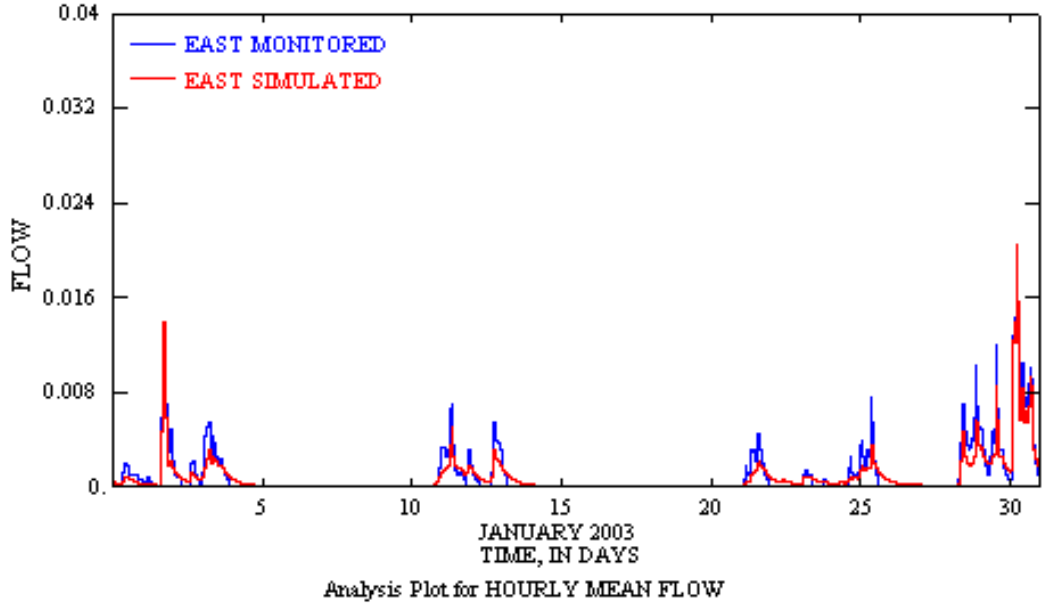

Figure 9. Portland Hamilton East Roof (January 2003)

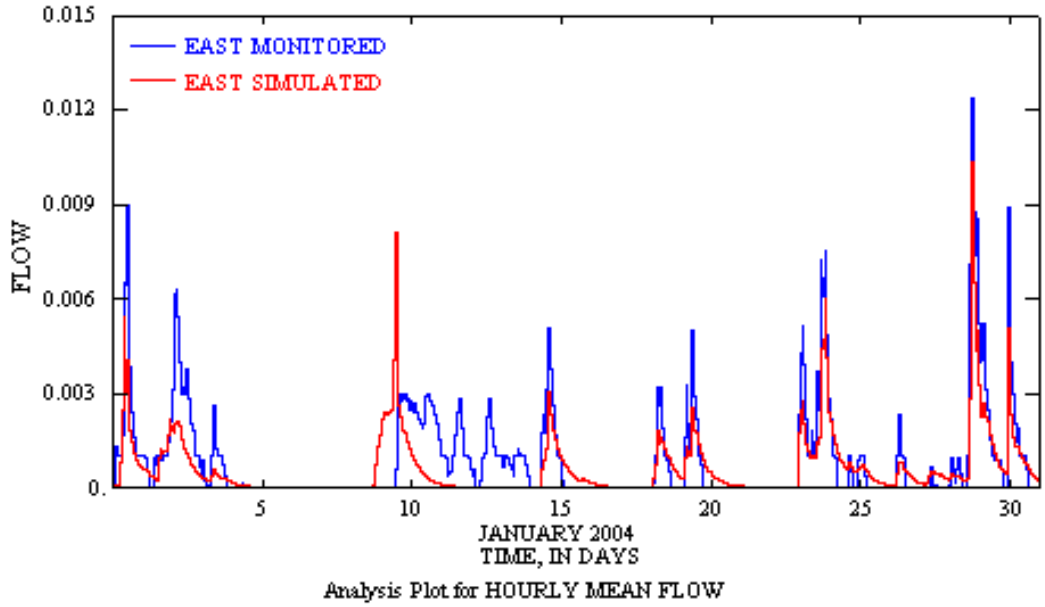

Figure 10. Portland Hamilton East Roof (January 2004)

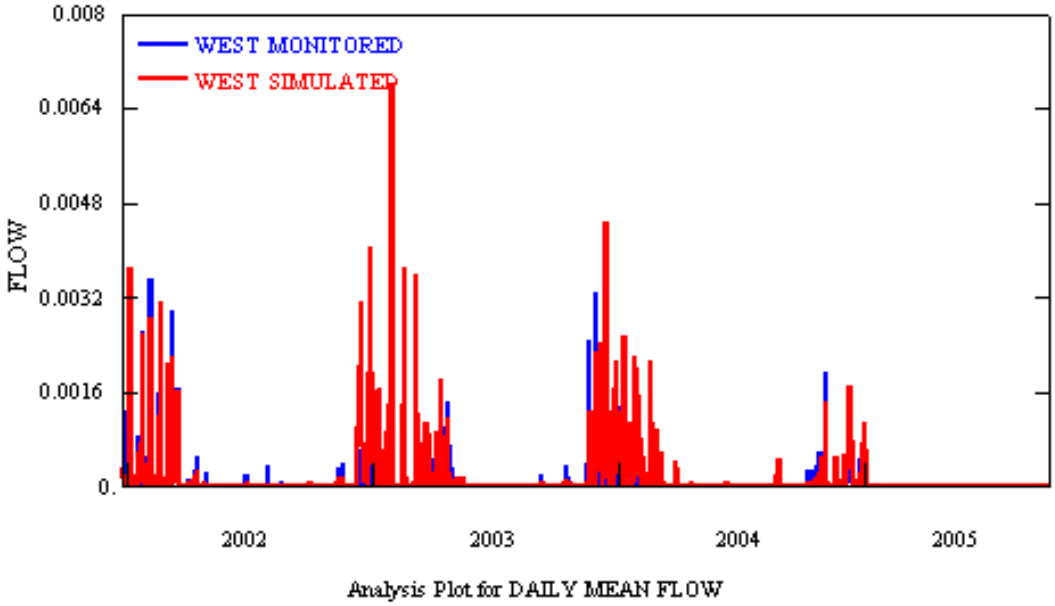

Figure 11. Portland Hamilton West Roof (2002-2005)

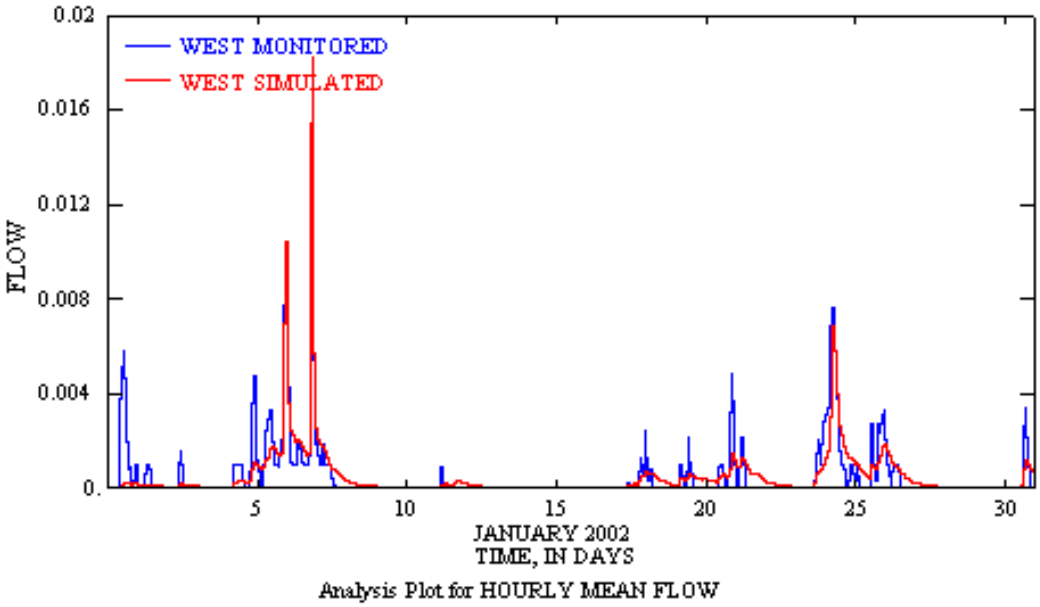

Figure 12. Portland Hamilton West Roof (January 2002)

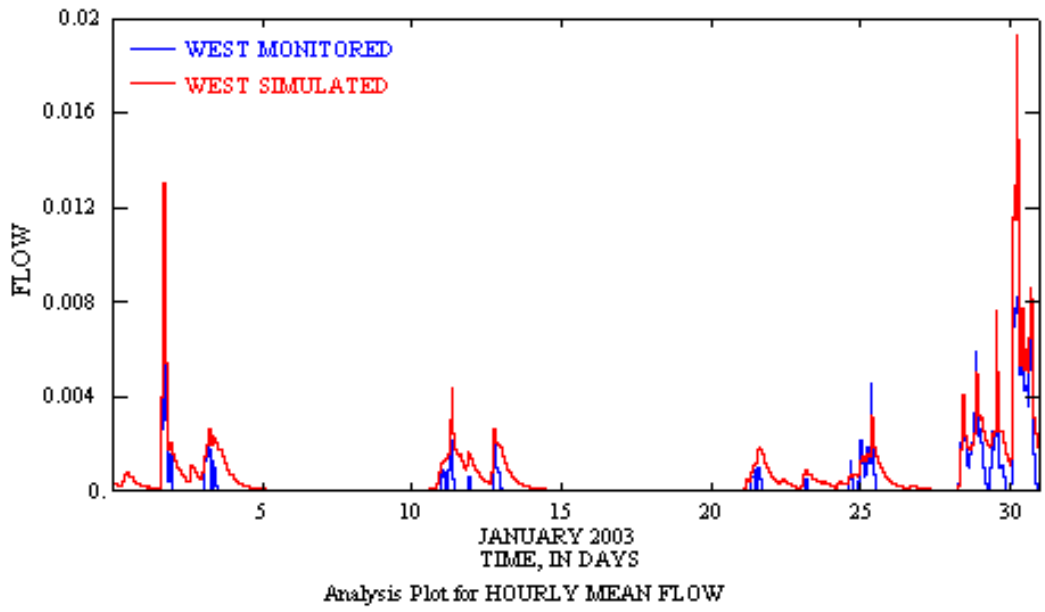

Figure 13. Portland Hamilton West Roof (January 2003)

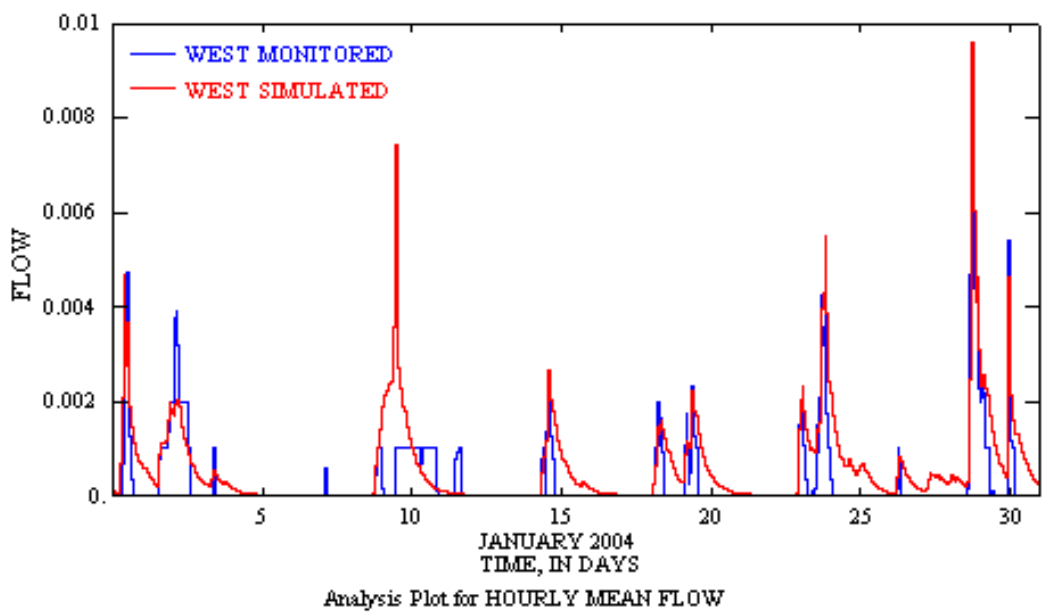

Figure 14. Portland Hamilton West Roof (January 2004)

Seattle Area Eco-Roof Results

The WWHM3 eco-roof parameters developed from the City of Portland data were used with Seattle area precipitation and evaporation data to compute long-term eco-roof runoff. These results were compared with the runoff from a conventional roof.

The WWHM3 includes SeaTac Airport hourly precipitation and Puyallup daily evaporation data for the period of October 1948 through September 1998. These two WWHM3 meteorological time series were used with the HSPF/WWHM3 parameter values calibrated with the Portland Hamilton runoff data.

Using the Seattle area meteorological data, the annual average rainfall is 38.08 inches. A conventional roof produces an average of 31.23 inches of runoff annually. In contrast, an eco-roof produces 25.21 inches of runoff. This is approximately a 19 percent reduction in runoff volume compared to a conventional roof and is equal to 5000 cubic feet of water per year for a 10,000 square foot roof.

Flow frequency was computed for the runoff from the same 10,000 sf roofs (eco-roof and conventional). Flow frequencies were computed by WWHM3 using Log Pearson Type III Bulletin 17B methodology. Results are shown in Table 2.

Table 2. Flow Frequency for 10,000 SF Roofs

Return Interval (years)	Conventional Roof (cfs)	Eco-Roof (cfs)	Reduction
2	0.0573	0.0433	24%
5	0.0697	0.0561	20%
10	0.0777	0.0641	18%
25	0.0877	0.0737	16%
50	0.0951	0.0806	15%
100	0.1024	0.0872	15%

Flow durations were also computed. The results are shown in Figure 15 below.

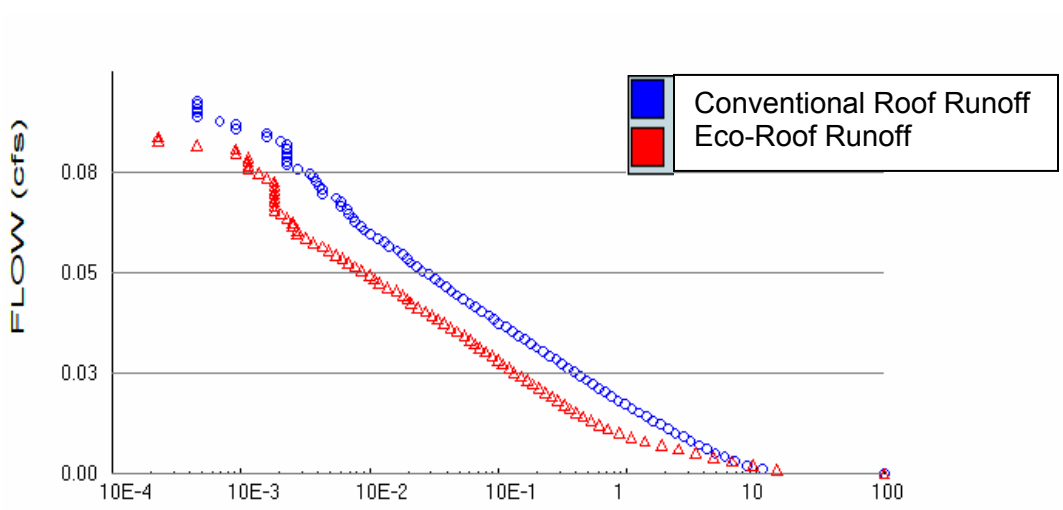

Figure 15. Flow Duration for Conventional and Eco-Roof

The flow duration results show that there is a reduction in the percent of time exceeded for roof runoff from conventional (blue) to eco-roof (red) for all ranges of flow, not just peak flow events.

Representative individual flow events were compared for the eco-roof and conventional roof to demonstrate the effectiveness of the eco-roof in decreasing and delaying stormwater runoff. As shown in Figures 16 and 17, the eco-roof flow produces lower runoff peaks and the timing of the peak is delayed approximately an hour, depending on the rainfall distribution and timing.

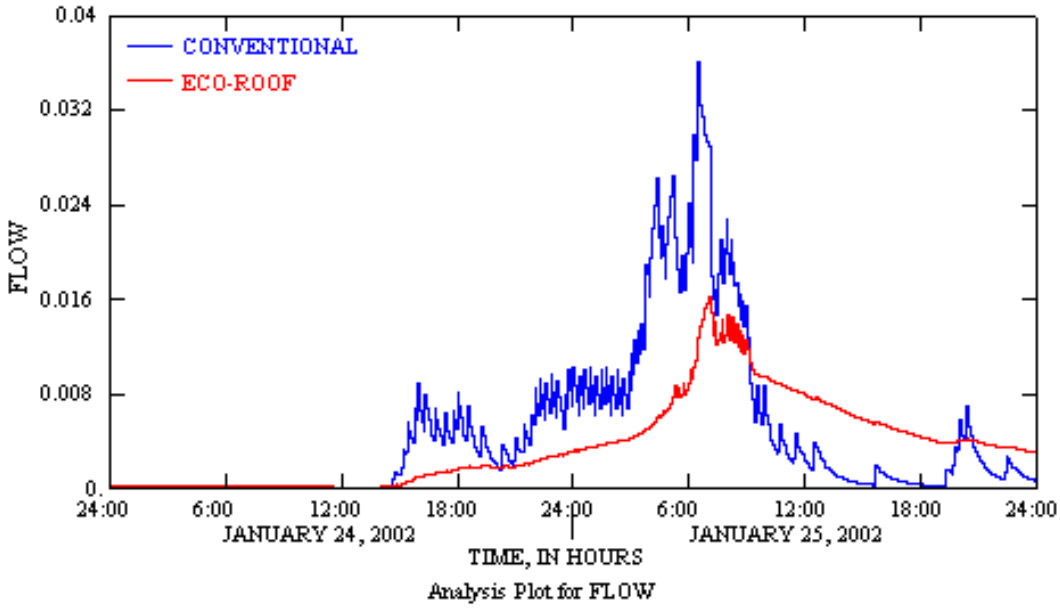

Figure 16. Comparison of Conventional and Eco-Roof Runoff (January 25, 2002)

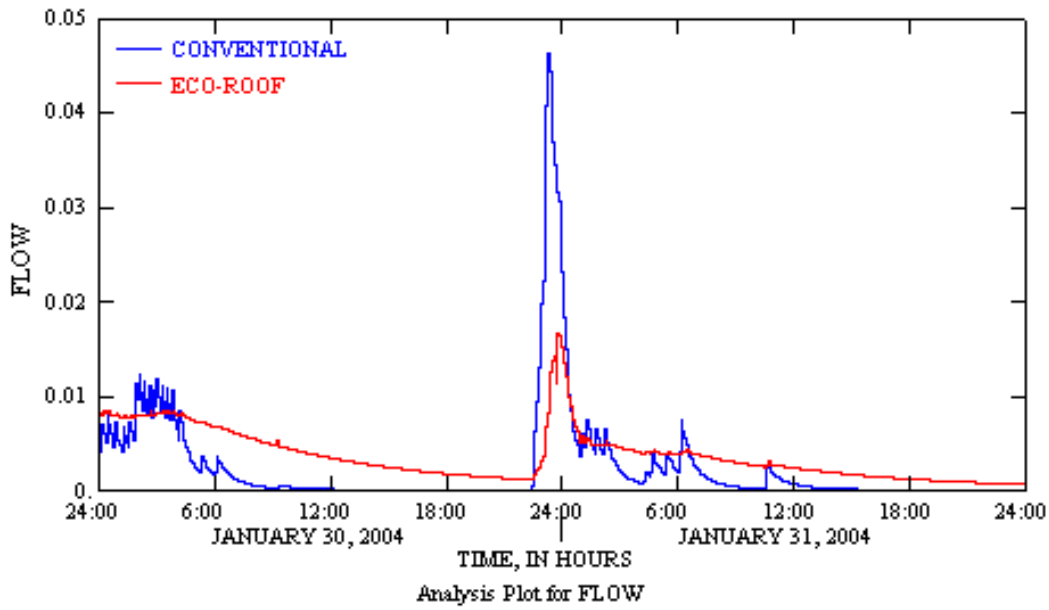

Figure 16. Comparison of Conventional and Eco-Roof Runoff (January 31, 2004)

<u>Summary</u>
The Portland Hamilton Building's east and west eco-roofs were modeled with the new WWHM3 eco-roof element. One set of calibrated HSPF parameter values were determined based on the need to have representative values for average soil/substrate conditions. With these restrictions the calibrations were good in reproducing monitored runoff from the two eco-roofs.

The calibrated set of WWHM3 eco-roof values were used with Seattle meteorological data to determine the stormwater effects of a Seattle eco-roof compared to a conventional roof. The results showed approximately a 20% reduction of runoff volume and flow frequencies. Flow durations are also decreased. The runoff peak is delayed approximately one hour.

Conclusions
The WWHM3 eco-roof element is the most accurate computer tool available to continuously simulate the hydrology of eco-roofs. It is a better and more accurate methodology than previously made assumptions to represent an eco-roof as a natural soil column (till, lawn).

The accuracy of the WWHM3 eco-roof element is dependent on the soil/substrate of the eco-roof. The Portland Hamilton eco-roof data shows that different substrate produce different runoff.

Recommendations
We recommend that the WWHM3 eco-roof element be used by SPU to evaluate the stormwater effectiveness of eco-roofs in the City of Seattle.

We also recommend that additional calibration of the WWHM3 eco-roof parameter values be conducted for different soils/substrates when and where sufficient monitoring data are available.

References

Hutchinson, D., Abrams, P., Retzlaff,R., and Liptan, T. 2004. Stormwater Monitoring Two Ecoroofs In Portland, Oregon, USA. City of Portland, Bureau of Environmental Services.